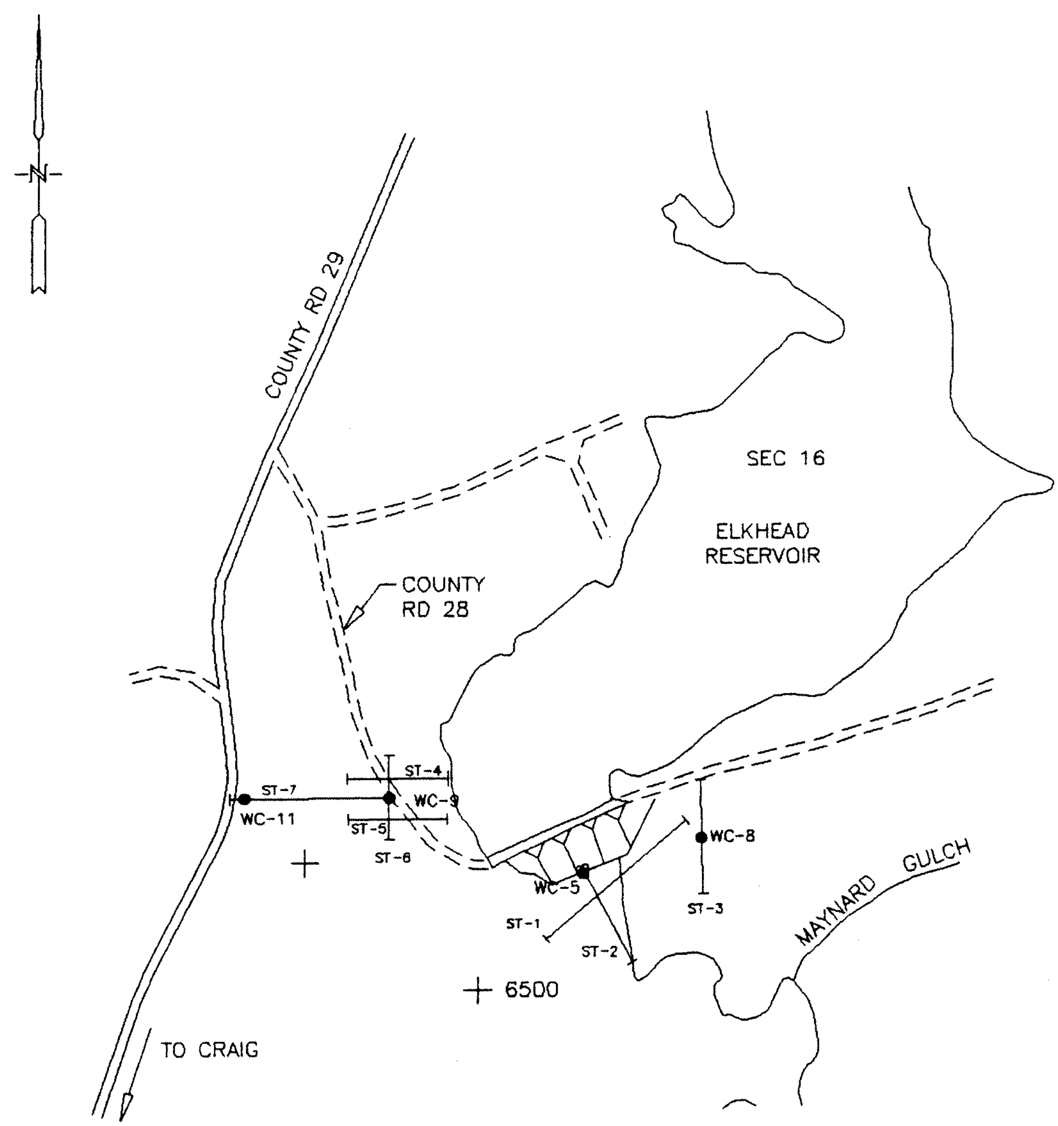


Approximate scale 1" = 900 ft.

LEGEND:

ST-2 Seismic Traverse

WC-8 Exploration Boring

note:
all line locations are approximate

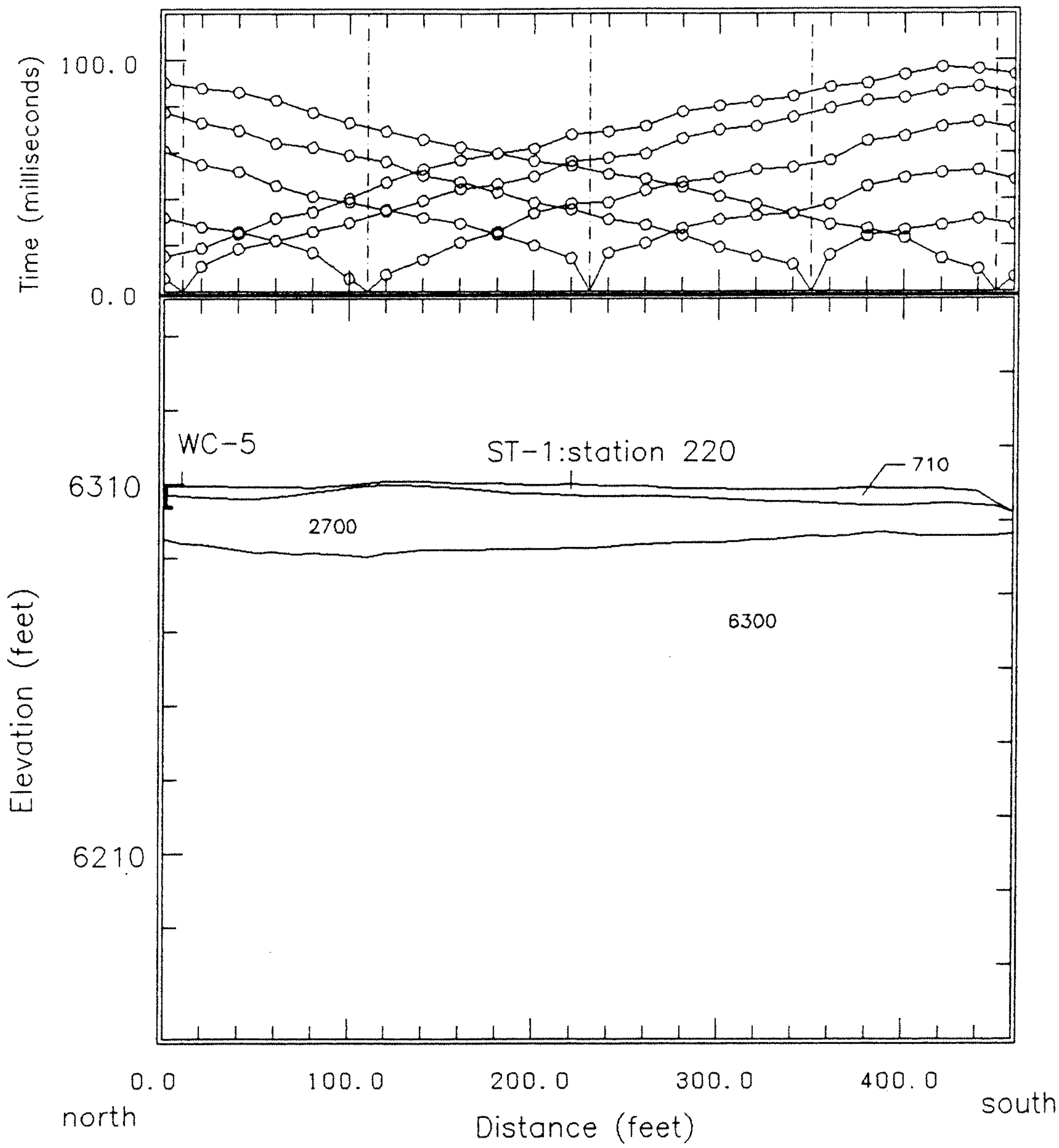
Muller Engineering Company

Seismic Traverse Line Location Map

Elkhead Dam, Moffat County, Colorado

Hadley & Hollingsworth Ltd.

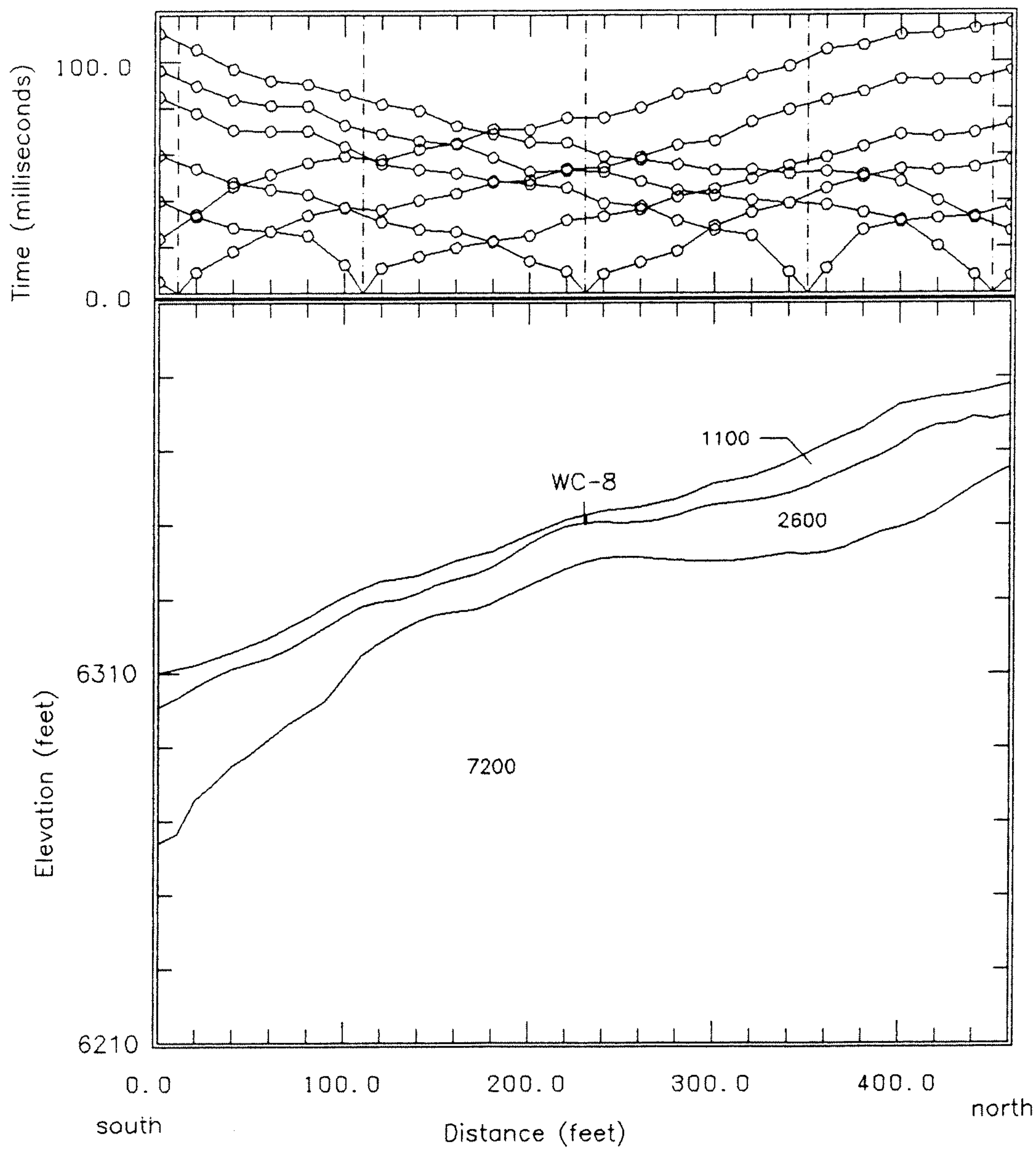
August 1993	Job# 93-39	Figure 1



Elevation reference datum: 6310 (est.)

6400 - seismic velocity
(feet per second)

Elkhead Dam, Moffat County, Colorado		
Refraction Seismic Line ST-2		
Hadley & Hollingsworth Ltd.		
August 1993	Job#93-39	Figure 3



Elevation reference datum: 6310 (est.)

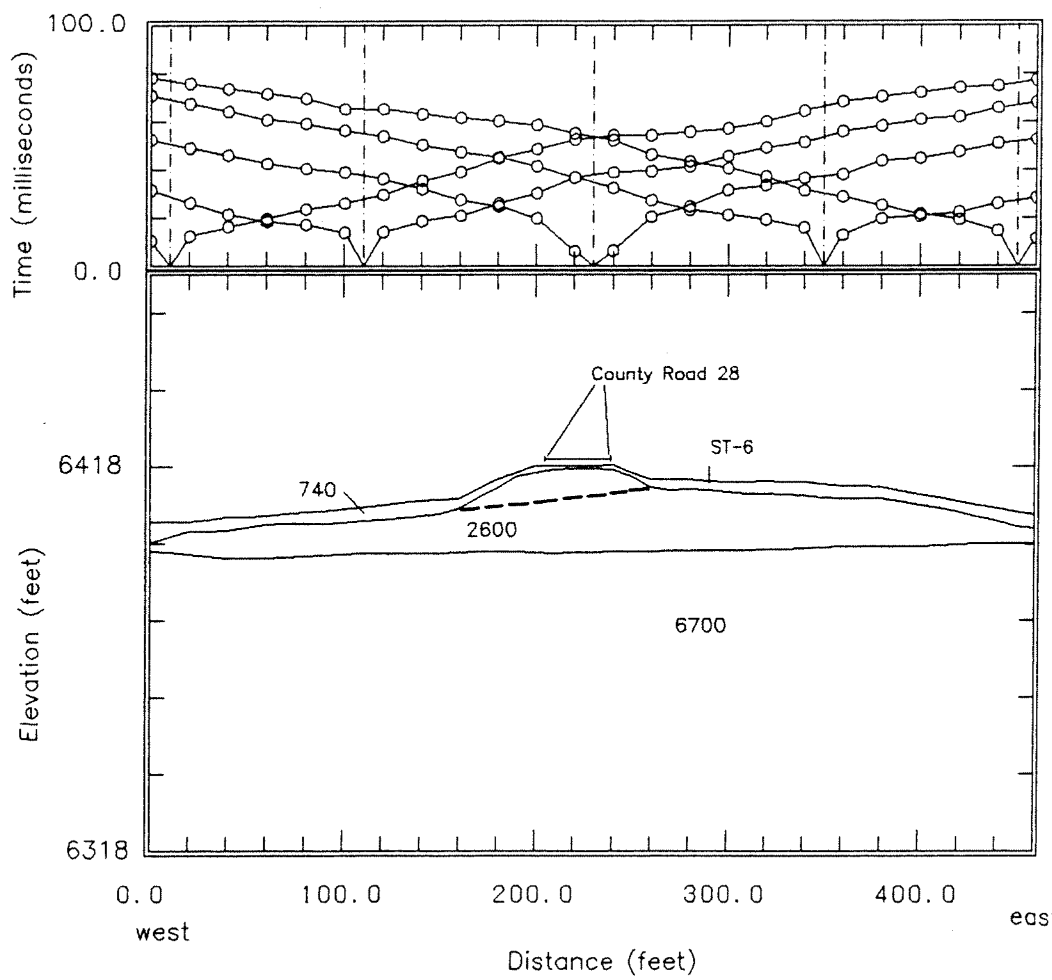
6400 - seismic velocity
(feet per second)

Elkhead Dam, Moffat County, Colorado

Seismic Refraction Line ST-3

Hadley & Hollingsworth Ltd.

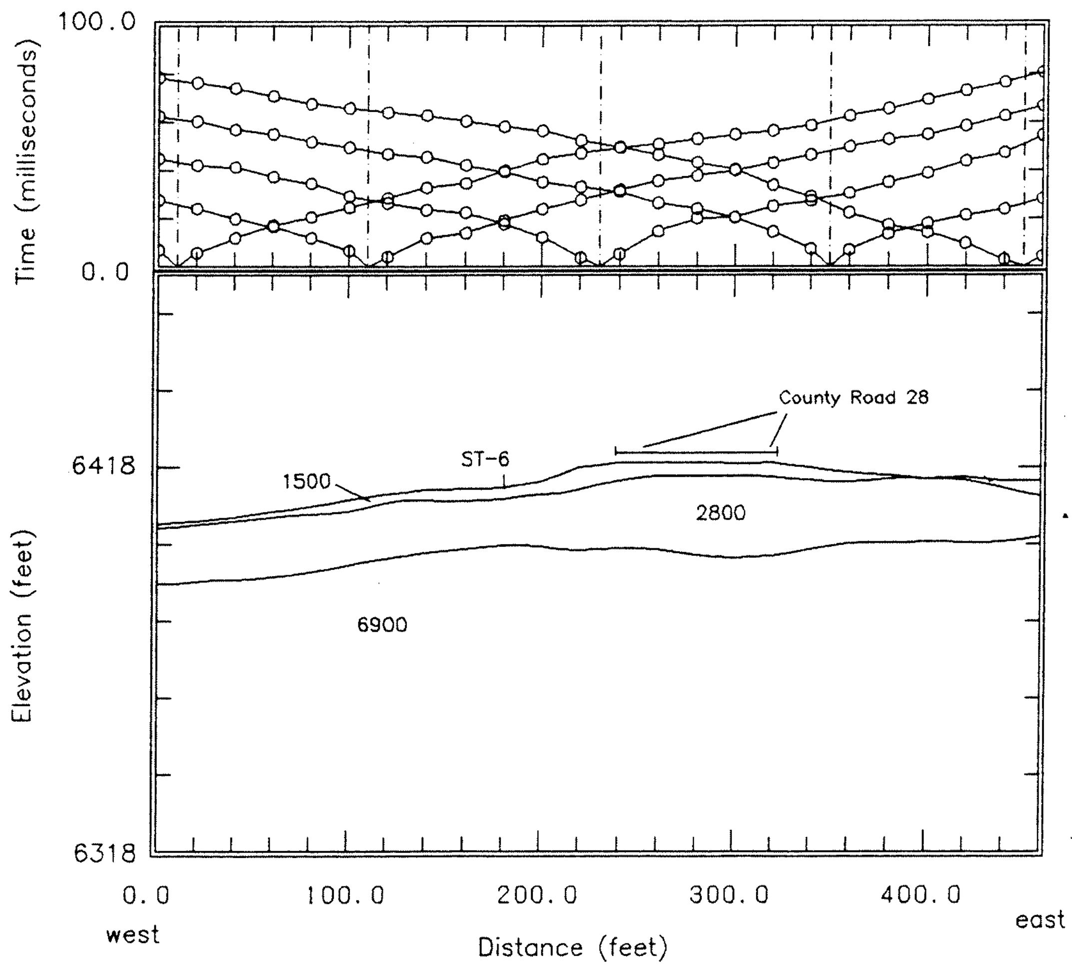
August 1993	Job#93-39	Figure 4



Elevation reference datum: 6418

6400 – seismic velocity
(feet per second)

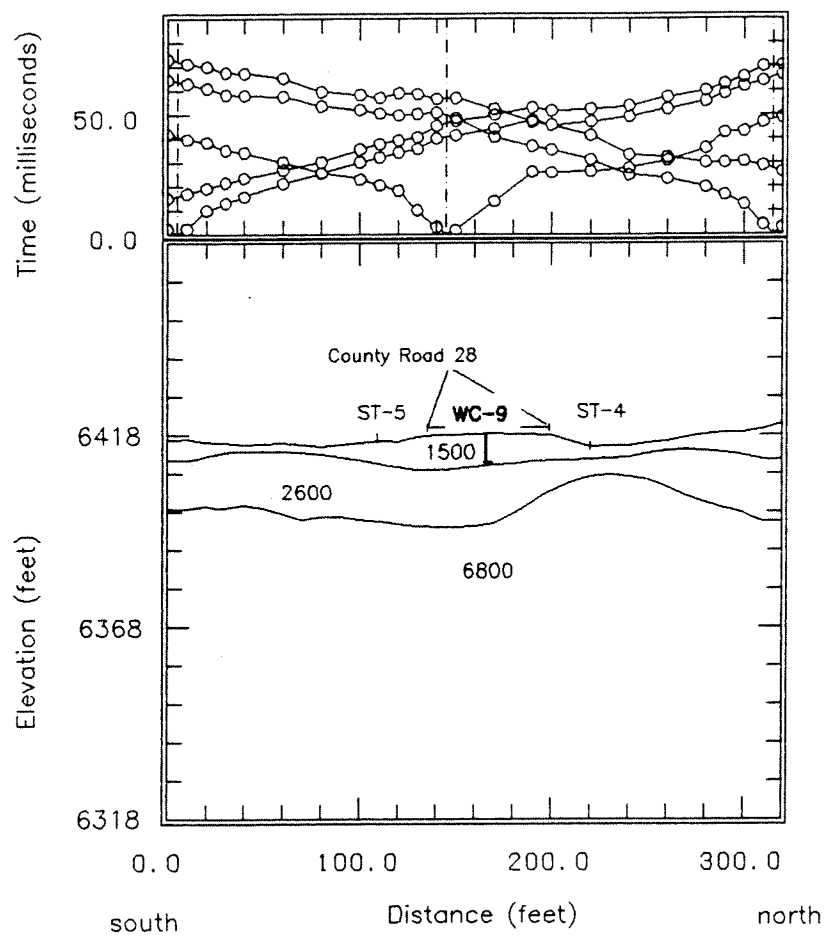
Elkhead Dam, Moffat County, Colorado		
Seismic Refraction Line ST–4		
Hadley & Hollingsworth Ltd.		
August 1993	**Job#93–39**	**Figure 5**



Elevation reference datum: 6418 (est.)

6400 - seismic velocity
(feet per second)

Elkhead Dam, Moffat County, Colorado		
Seismic Refraction Line ST-5		
Hadley & Hollingsworth Ltd.		
August 1993	**Job#93-39**	**Figure 6**

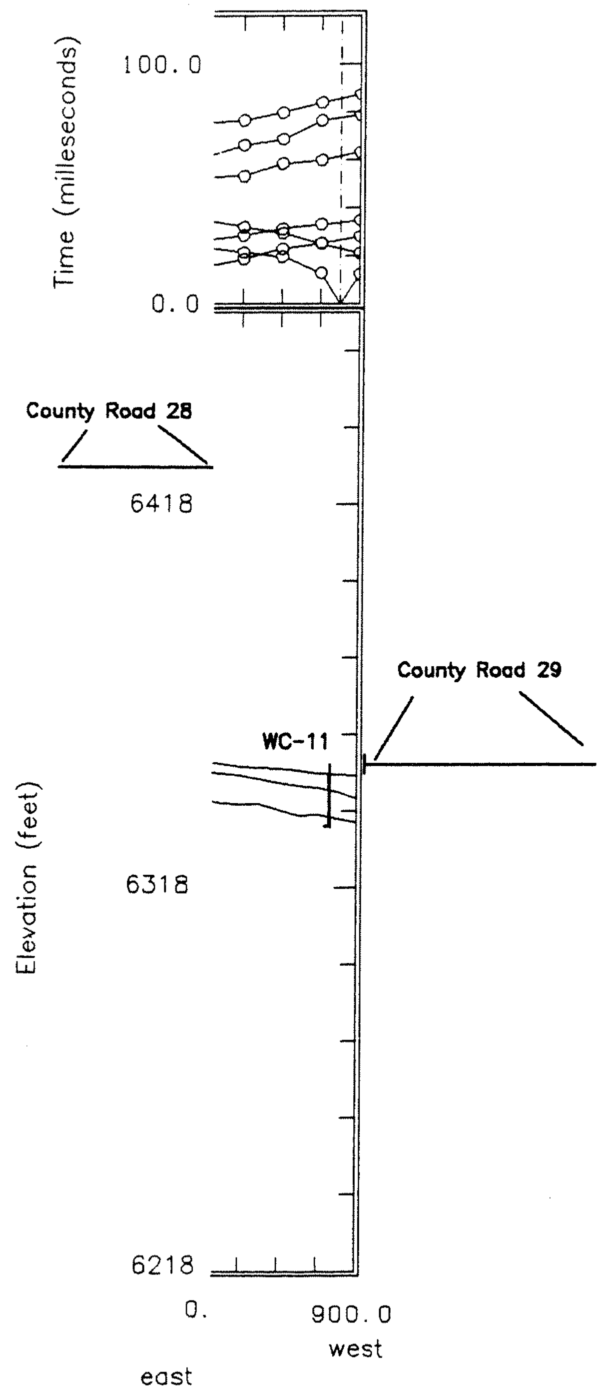


Elevation reference datum: 6418 (est.)

ST-4 - seismic traverse line

6400 - seismic velocity (feet per second)

Elkhead Dam, Moffat County, Colorado		
Seismic Refraction Line ST-6		
Hadley & Hollingsworth Ltd.		
August 1993	**Job#93-39**	**Figure 7**



Elkhead Dam, Moffat County, Colorado

Seismic Refraction Line ST-7

Hadley & Hollingsworth Ltd.

August 1993	Job#93-39	Figure 8

HADLEY & HOLLINGSWORTH, LTD.
APPLIED EARTH SCIENCES

SEISMIC REFRACTION SURVEYS

ELKHEAD DAM

MOFFAT COUNTY, COLORADO

Prepared for

Muller Engineering
550 S. Wadsworth, Suite 500
Lakewood, Colorado 80226-3118

Job No. 93-39
September 13, 1993

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INTRODUCTION

Hadley & Hollingsworth, Ltd. was contracted by Muller Engineering Inc. to conduct approximately 4,000 feet of seismic refraction profiling around the existing Elkhead Dam near Craig, Colorado. The dam is to be enlarged and the purpose of the seismic refraction investigation was to map the top of rock in order to provide information for design. In addition to determining depth to bedrock, seismic velocities of the materials will be used to determine rippability of the various materials. Seismic line locations were selected by Woodward - Clyde Consultants and are shown on Figure 1. The field work was conducted from July 27 through July 31, 1993.

FIELD PROCEDURE

The seismic data were collected using industry standard techniques. An Oyo MX-160 24-channel, signal enhancement seismograph was used to record the information. The data were recorded on 3.5-inch diskettes for later analysis and a paper record was also generated as backup.

The data for each seismic line were collected in separate 24-channel "spreads" generally consisting of 24 vertical geophones laid out at 20-foot intervals. Surface elevations for each geophone were obtained by hand level surveys and tied to existing borings. A sledgehammer impacted on a metal plate was used as an energy source. Multiple blows were recorded and stacked digitally to obtain sufficient energy. In most cases record quality was acceptable. Hammer points (referred to as "shotpoints") were located at each end, in the middle and offset from each end in order to obtain coverage on the target refractor. The offsets were generally 40 feet or more in order to obtain arrivals from the refractor.

Stationing for each line was established by taping slope distances between stakes marking the ends of each seismic line. Elevations for each geophone were obtained by hand-level surveys tied to Woodward - Clyde drill holes.

INTERPRETATION

The data were downloaded from the diskettes to a computer in order to pick first arrivals from the records. Initial records were picked, plotted and interpreted in a preliminary manner the first day in the field in order to determine that the project objectives were being met and to make sure that the field data acquisition procedures were appropriate. Daily field record inspection indicated no major changes in site conditions. The first arrivals were plotted versus distance to obtain time-distance (T-D) graphs for analysis. Inspection of the T-D graphs provides a basis for determining the number of seismic layers and for calculating compressional wave velocities for each layer.

Software supplied by Oyo (SEISREFA) was used to analyze the data. This program uses ray-tracing techniques to interactively match the interpreted subsurface model to the field data. When the data are acquired in the proper format in the field, the interpretation method allows the computation of a depth to the bedrock refractor beneath each geophone. The solution is straightforward when only one layer overlies the bedrock, a model usually referred to as a "two-layer" case. In this situation, all the variations in the observed travel times are due to either a difference in thickness or a change in velocity of the upper layer. Since the uppermost layer velocity is generally well defined by the direct arrivals, the overburden thicknesses are easily calculated. However, when two layers overlie bedrock (a three-layer case), velocity of the middle layer is less well defined and it is more difficult to determine whether the time variations are due to velocity variations or are due to thickness changes in the first or second layers.

In addition, it appears that in most areas at the dam site the top of the bedrock is not a sharp erosional contact, but a gradual transition from weathered to more competent bedrock. This results in a gradual increase in velocity with depth which also complicates the refraction interpretation. This type of problem is not often obvious on the field records, but shows up later in the analysis.

RIPPABILITY

To evaluate the potential for ripping the bedrock, the CATERPILLAR Ripper Performance Chart for a D9N, shown as Table I, was referred to. For sedimentary rocks, the chart indicates velocities below 7,200 fps represent rippable rock, velocities of 7,200 fps to 9,200 fps represent marginal conditions, and velocities over 9,200 fps represent non-rippable rock. The rippability of a material is determined primarily by the rock density, but is also affected by the amount and spacing of fracturing and the type of excavation. Many materials shown as rippable on the chart are only rippable in large, open excavations. Although the compressional wave velocity of a material decreases with decreased density and increased fracturing, the seismic velocity can be affected by other factors. The compressional wave velocity is a good indicator of rippability; however rippability should always be evaluated using seismic velocity, visual inspection and field tests where possible.

RESULTS

A seismic cross-section was computed for each refraction spread. Two spreads were required on seismic lines ST-1 and ST-7 to cover the specified length of line. The two spreads were combined to form a single depth profile for each seismic line. The cross-sections for each seismic line are shown on Figures 2 through 8. Each figure shows the time distance graph with the interpreted depth section below. The horizontal scale is 1 inch = 100 feet and the vertical scale is 1 inch = 50 feet resulting in a 2:1 vertical exaggeration. This was done to emphasize topographic detail on the bedrock surface. Stationing along each line is for reference only and is not related to any site survey points.

In general, the seismic lines indicate three layers. Downstream of the existing dam, Lines ST-1 and ST-2 indicate two layers over the bedrock. Based on drill hole information, these layers are believed to be unsaturated alluvium on the order of 10 to 20 feet thick. Bedrock velocities range from 5,500 to 6,400 feet per second (fps). The remaining seismic lines are generally on side slopes or uplands. These lines show variable depths to bedrock which range from 0 to over 40 feet. The bedrock generally exhibits a compressional wave velocity in the range of 7,000 fps. The overlying moderate velocity materials in the range of 3,000 fps are believed to be weathered bedrock based on available drill hole information. A more detailed description of each seismic line is provided below.

Line ST-1

Line ST-1 was conducted downstream of the existing dam and consists of two spreads. Spread 1 indicates three layers. The upper layer has a velocity of 1,200 fps and is believed to consist of loose surface soils. The intermediate layer exhibits a velocity of 3,000 fps. Based on drill hole WC-5 on Line ST-2, this layer may consist of both unsaturated alluvium and weathered bedrock. The combined thickness of the two upper layers is generally about 20 feet. The underlying sound bedrock has a velocity of 5,500 fps. Spread 2 starts at the creek and extends up the left abutment slope. This spread also indicates three layers. However, it is believed that at some point the intermediate layer changes from alluvium to weathered bedrock. Sound bedrock with a velocity of 6,400 fps underlies the upper two layers at an average depth of about 10 feet. All the materials encountered along Line ST-1 should be rippable, including at least the upper 10 feet of bedrock.

Line ST-2

Line ST-2 starts at the downstream toe of the existing embankment and extends downstream crossing Line ST-1 at distance 220 feet on both lines. Line ST-2 indicates three layers similar to Line ST-1. The upper layer is about 2 to 5 feet thick and has a compressional wave velocity of 710 fps. This material probably consists of loose surficial soils. Based on the available drill hole data, the intermediate velocity material with a velocity of 2,700 fps is believed to consist of unsaturated alluvium and weathered bedrock. It appears that there is insufficient velocity contrast between the two to observe a distinct boundary. The sound bedrock is generally about 15 to 20 feet deep and exhibits a velocity of 6,300 fps. All the materials encountered along Line ST-2 should be rippable, including at least the upper 10 feet of bedrock.

Line ST-3

Line ST-3 was conducted in the left abutment area along the axis of the proposed new spillway. This line also exhibited three layers. The upper layer, with a velocity of about 1,100 fps, is believed to consist of surficial soils and/or colluvium. This layer is generally less than 5 feet thick. The intermediate layer with a velocity of 2,600 fps is believed to be weathered bedrock, based on drill hole WC-8. The bedrock velocity of 7,200 fps indicates somewhat denser or harder material than encountered in the stream valley. All the materials with velocities less than 7,200 fps should be rippable. The sound bedrock velocity is in the marginal category and should be rippable in open excavations. Narrow trenches may require other methods.

Line ST-4

Line ST-4 was conducted in the area of the proposed emergency spillway crest. It is the northernmost line starting west of County Road 28 and extending east across the road and down the slope towards Elkhead Reservoir. This is the north edge of a topographic saddle that the road was constructed through. Line ST-4 exhibits 3 layers. The first layer is a thin, layer with a velocity of 720 fps which is believed to consist of loose surficial soils. The intermediate layer exhibits a velocity of 2,600 fps and is thought to consist of weathered bedrock and moderately dense fill material used to construct the road bed based on drill hole WC-9. This layer thins to the east and west of the road. The depth to unweathered bedrock averages about 7 feet. The bedrock velocity of 6,700 fps indicates that all the materials encountered along ST-4 should be rippable, including at least the upper 10 feet of bedrock.

Line ST-5

Line ST-5 was also conducted in the area of the proposed emergency spillway crest. It is the southernmost line starting west of County Road 28 and extending east across the road and down the slope toward Elkhead Reservoir. This line also exhibits 3 layers. The first layer is a low velocity layer of 1,500 fps and is believed to consist of loose surficial soils. The thickness of this layer ranges from 0 to 5 feet. The intermediate layer exhibits a velocity of 2,700 fps and is believed to consist of weathered bedrock, based on drillhole WC-9 which is north of the line. The third layer is believed to consist of unweathered bedrock and exhibits a velocity of 6,800 fps.

The combined thickness of the upper two layers varies from 10 to 20 feet. All the materials encountered along Line ST-5 should be rippable, including at least the upper 10 feet of bedrock.

Line ST-6

Line ST-6 was also conducted in the area of the proposed emergency spillway crest. It begins south of County Road 28 and extends north across County Road 28. This line intersects lines ST-5 and ST-4 and is situated just east of WC-9. This line also exhibits 3 layers. The first layer is a low velocity layer of 1,500 fps and is believed to consist of loose surficial soils. The thickness of the upper layer is generally less than 10 feet. The intermediate layer exhibits a velocity of 2,600 fps and is believed to be weathered bedrock, based on drillhole WC-9. The third layer is unweathered bedrock exhibiting a velocity of 6,800 fps. The depth to sound bedrock is variable, ranging from 10 to 24 feet, but is generally around 20 feet. All the materials encountered along Line ST-6 should be rippable, including at least the upper 10 feet of bedrock.

Line ST-7

Line ST-7 was conducted along the length of the proposed emergency spillway channel. It extends from drillhole WC-9 on the west edge of County Road 28 west to drillhole WC-11 on the east edge of County Road 29. The line consists of two spreads. Spread 1 indicates a four-layer case and Spread 2 indicates a three-layer case.

The upper layer on both spreads has a velocity of about 900 fps. On Spread 1, this upper layer overlies an intermediate layer of 1,500 fps which appears to pinch out on the east end of the line. The velocity of these two layers is consistent with loose to moderately dense surficial soils and colluvium. These two upper layers vary in thickness from a few feet to around 10 feet near center of the line. The more continuous intermediate layer exhibits a velocity ranging from 2,900 fps on Spread 1 to 3,100 fps on Spread 2. Drilling information from WC-9 and WC-11 suggest that this layer is a combination of moderately dense colluvium and weathered bedrock. It appears that this layer is weathered bedrock on the upper (east) end of the line and transitions to colluvium on the west end of the line. The thickness of this layer is variable, but is generally around 20 feet, becoming somewhat thicker in the center of the line, and thinner on the east end.

The third layer is unweathered bedrock exhibiting velocities in the range of 7,000 to 7,600 fps. All the materials lying above the sound bedrock should be rippable. The bedrock velocity is in the range of marginal rippability on the west end of the line. Rippability in this area will depend on the type of excavation, orientation of the excavation to planes of weakness in the rock and possibly other factors which cannot be adequately evaluated in this report.

TABLE I

RIPPER PERFORMANCE

D9N

- **Multi or Single Shank No. 9 Ripper**
- **Estimated by Seismic Wave Velocities**